

AN OPERATIONS CONCEPT METHODOLOGY TO ACHIEVE LOW-COST MISSION OPERATIONS

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ABSTRACT

Historically, the Mission Operations System (MOS) for a space mission has been designed last because it is needed last. This has usually meant that the ground system must adjust to the flight vehicle design, sometimes at a significant cost. As newer missions have increasingly longer flight operations lifetimes, the MOS becomes proportionally more difficult and more resource-consuming. We can no longer afford to design the MOS last. The MOS concept may well drive the spacecraft, instrument and mission designs, as well as the ground system. This paper presents a method to help avoid these difficulties, responding to the changing nature of mission operations. It is this paper's thesis that proper development and use of an Operations Concept document results in a combined flight and ground system design yielding enhanced operability and producing increased flexibility for less cost.

Key Words: Operations concept, mission operations, mission control, operational requirements, program phases.

1. INTRODUCTION

For most missions, beginning the design of the Mission Operations System (MOS) occurs only after the spacecraft and mission design are well established. It is difficult for a project to consider operational issues that impact the program several years in the future when attention is focused on an immediate spacecraft design or fabrication problem. When early decisions impacting the ground system are made by spacecraft, instrument or mission designers without input from MOS designers, difficulties in MOS design and implementation arise. As a result, costly solutions are sometimes necessary. An example of this was the way telemetry from the Viking lander experiments was packaged

into different sized, independent data frames rather than packetized into a master frame. The seismometry frame was even variable in length. The signature of a marsquake could be adequately captured only by a high sampling rate, therefore the seismology data frame was designed with the unique capability to expand to a larger number of bytes if a quake were to trigger the instrument. This innovative idea may have served the experiment well during operations, but the design of the telemetry frame synchronization process on the ground was made unnecessarily complicated because of variable length data frames.

With recent concerted emphasis on reducing the cost of space programs, the contribution due to designing and building the MOS has to be considered along with that of designing and building the spacecraft. James S. Martin, NASA consultant and former Viking Project manager has said, "As more and more missions are planned to have flight operations lifetimes measured in years, even tens of years, the MOS becomes an increasingly more difficult, more costly, and more human resource limited process. No longer can we afford to design the MOS last. In fact, the MOS concept may well drive the spacecraft design, the science instrument design, and the ground system." (From the Foreword to Ref. 1)

There has been recent progress toward involving the MOS designers in the process of spacecraft and mission design from the beginning. This paper describes how a key document, the *Operations Concept*, can assist this process. Proper development and use of the Operations Concept can result in the designs of the combined flight and ground system yielding enhanced operability, thereby producing increased flexibility for less cost. Discussion of the Operations Concept is best made in the context of standard program phases, reviews

and documentation. However, since these vary between NASA centers, the following section will define the context for this paper.

2. PROGRAM PHASES AND REVIEWS.

The four phases of a program's life cycle are: (1) *system planning*, which comprises feasibility analysis, concept development, requirements definition, and the development of a system acquisition plan; (2) *system development*, which includes requirements analysis, concept evaluation, preliminary and detailed design, implementation, and test activities through acceptance testing; (3) *integration and test*, which encompasses the integration of systems into the overall MOS and complete testing of the integrated systems against all the specified requirements; and (4) *system operations*, which consists of flight operations support, beginning with launch operations.

In spite of the extra work they cause for the system designers, formal reviews of the progress of the project before a board of experts are essential to resultant design excellence. A series of reviews should be held, independently for the spacecraft and for the MOS. Figure 1 illustrates the timing of various reviews with respect to the program phases. During the System Planning phase, there should be a *Preliminary Requirements Review* (PRR) after the initial requirements definition is complete, to assess whether or not the requirements are well defined. Historically, more projects have gotten into serious difficulties due to incomplete or ambiguously defined requirements than any

other cause. A *Preliminary Concept Review* (PCR) is recommended after the full system operations concept is developed.

During the System Development phase, a *System Requirements Review* (SRR) and the resolution of action items that follow will finalize the requirements and evaluate readiness for design to begin. After preliminary system design is complete, a *Preliminary Design Review* (PDR) is held. The preliminary design should be approved before detailed design can begin. When the design is complete, the *Critical Design Review* (CDR) is the milestone preceding procurement of hardware and start of actual implementation. In practice, multiple CDRs are usually held for various components of the system, due to the additional detail and differing review board expertise. Unfortunately, many times the design begins before the requirements are finalized, the project bowing to time and schedule pressure. A well developed concept of operations will help definitize the requirements early. Minimizing the amount of design accomplished before finalizing requirements lowers the ultimate cost of the system by eliminating redesign.

During the Integration and Test phase, there are many reviews of specific activities to ensure the implementation and testing is proceeding according to plan. MOS components, consisting of both hardware and software, are incrementally delivered after each has completed its user acceptance testing. However, when the fully developed MOS ground system is ready to be delivered, an *Acceptance Test Review* (ATR) is held. The ATR reviews the testing against the original requirements and against the operations concept. Once all MOS subsystems are delivered and the flight operations team is selected and trained, the *Operations Readiness Review* (ORR) is held to verify that the entire MOS, including the people who will operate it, is ready for operations to begin.

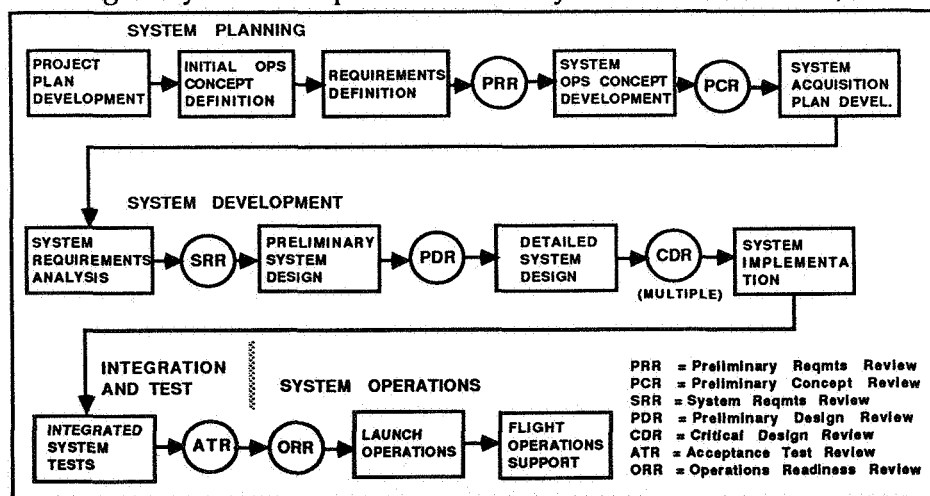


Figure 1 - Program Phases and Reviews

For small projects where costs are severely limited and the complexity of flight components and ground systems are not as great, the reviews may also be less expansive in scope. (As an example, the preliminary concept may be reviewed at the same time as the preliminary requirements, effectively combining the PRR and PCR.) Although some reviews may be combined, it is important not to omit the actual step from the process, for the efficiency of the resulting design depends on orderly execution of the design and implementation process.

3. OPERATIONS CONCEPT.

An Operations Concept is an orderly collection of user-oriented ideas as to how the operations system should function to satisfy the mission and experiment objectives. Although the concept can exist without being documented, a written version ensures uniform dissemination of the concept. The assumption here is that the Operations Concept is a summary document describing the collection of ideas that form the concept.

The Operations Concept is an evolving document, with a purpose and function that changes with the program phases. Its initial and most important function is that it (1) *drives the program design* toward one that will satisfy the mission and experiment objectives. Written early in the system planning phase, this initial version establishes and clarifies the intended operational approaches. As the design of the operations system is developed, the Operations Concept (2) *guides the design engineers* by shaping the definition of system requirements and keeping the focus on system operability. With additions and configuration-controlled revisions as necessary, the Operations Concept, at the end of the design phase, (3) *becomes a summary description of the design*, illustrating the way the operations system will be used to conduct mission operations. The objectives of the Operations Concept and its uses are indicated by the following nine items, each allocated to one of the above three document purposes.

As a design-driving document, the Ops Concept:

1. *Summarizes the primary objectives and constraints for both the mission and experiments.* These basic goals are established by the project scientists and mission planners and

become an input to the system planning phase.

2. *Documents early the intended operational approaches.* Basic operational philosophy delineated early in the planning phase will simplify subsequent tasks and establish design requirements.

3. *Defines how users will operate and maintain the system.* The domain of user activities is defined. System operations, system maintenance and required institutional support are all addressed early enough to influence the design requirements.

As a design-guiding document, the Ops Concept:

4. *Becomes the unifying document for the requirements analysis and design phases.* By clearly defining the operational use of the system, it serves as a reference for designers, communicating the operations strategies to project personnel as system definition and design proceed. Systems engineers will consult it for guidance to ensure the system design will satisfy the operator's requirements. It also provides a test bed where design issues can be raised and resolved.

5. *Clarifies operational interfaces early.* It identifies operations interfaces early enough in the program to ensure a common understanding and sufficient definition, resulting in a more efficient implementation. Interface identification also defines the environment for the integration test program by specifying which operational components must "play together."

6. *Provides a framework for trade and cost studies.* By defining and prioritizing necessary system operational features, the operations concept will provide criteria for evaluating trade study and cost options.

As a design-description document, the Operations Concept:

7. *Provides input for generation of plans and procedures.* It supplies information for various operations plans such as the Mission Data Plan (which describes the handling plan for downlinked information) and the Experiment Operations Plan (which explains how the experimenters will operate their instruments). It also provides input for generation of team operations plans and subsequent team activity procedures.

8. *Supplies test objectives for system integration tests.* This will ensure that the testing will prove the mission concept and that

the design will meet established requirements.

9. *Summarizes intended mission operations.* It always remains a concise, readable summary of the purpose and intended operation of the mission at any time during any phase, for either external or internal interests. It is required reading for new personnel and a valuable source of operations training material.

The initial version of the Operations Concept is written after only the rudimentary mission objectives have been determined, and in fact must be formed in parallel with those early mission concepts. As illustrated by Figure 2, it is generated from conceptual ideas of how the system will be operationally used to satisfy mission objectives. In most cases, this first version is written by the office funding the mission for attachment to requests for study proposals. Its purpose is to provide information from which a contracting company or university can proceed to develop science requirements, mission requirements and the operations design requirements that support them. At this stage, the contents are the objectives and constraints of both the mission and individual experiments, and the conceptual approaches to operations system activities. Once determined and agreed upon by the participants, the operational approaches that constitute this initial concept should be placed under configuration control. They cannot be

arbitrarily changed without the consent of all affected parties. This initial concept is a major source of operations design requirements generated as an input to the functional requirements documents.

Once the initial set of MOS design requirements are defined, the first version of a full Operations Concept document can be written and reviewed at the PCR. Figure 3 provides a sample outline for the content of this complete document, taken largely from Ref 2 with modifications. Although it is likely to have many incomplete sections for those areas where detail is dependent on a design selection, it will contain the basic concept for operating the system as it is initially envisioned. It will define at a high level the intended uplink process for planning, scheduling, generating, validating, and transmitting commands or sequences of commands, and the downlink process for receiving, monitoring, separating, and processing the telemetry. These strategies are not final at this stage but will evolve with the design.

In order to efficiently implement an Operations Concept, several ground rules need to be imposed during development. Adherence to these rules could make the difference between success and failure of the Operations Concept as a useful tool.

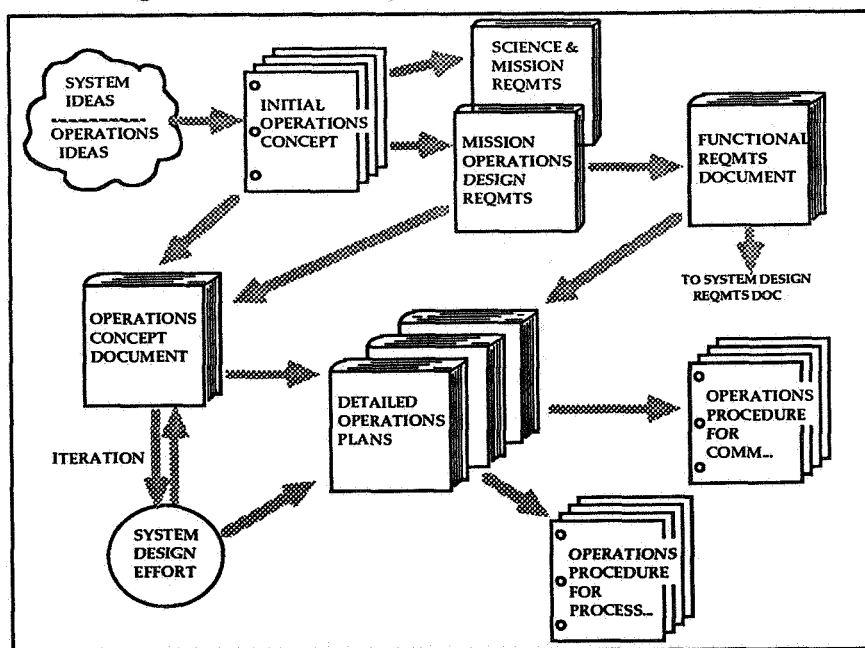


Figure 2 - Operations Planning And Development Flow

1. *Obtain early agreement on basic operational approaches.* It is more important that all the players agree on an approach, even if operationally less-than-optimal, than to have a perfect approach.

2. *Keep the document concise yet comprehensive.* It should be a summary of intended operations. It must cover all areas of operations necessary to accomplish the mission, but restricting details in each area to that essential to conveying the message.

3. *Keep it updated.* Revisions or additions, scheduled after major steps in the planning, design and

1. Introduction	Scope and Objectives of Document Organizational Roles and Responsibilities
2. Summary	Flight Vehicle and Ground System Configuration
3. Objectives, Constraints and Approaches	Mission Objectives and Constraints Experiment Operations Objectives Approaches to Operations Activities
4. Operations Requirements and Functions	Summary of Operations Requirements Functional Definition and Operations Flows Definitions of Operational Modes
5. Operational Activities and Scenarios	Activity Table and Timelines Normal Operational Scenario
6. Contingency Operations	
7. Operational Interfaces	Interfaces External to System Interfaces Internal to System Human-Computer Interfaces
8. Operational Hardware Features	User Equipment & Operations Console Features Communications Nets and Data Links Special Facility Requirements
9. Personnel Component	Operational Positions and Responsibilities Organization and Support Coverage Training Concept
10. Reliability, Maintainability and Availability	System Reliability and Availability Maintenance and Logistics Concepts

Figure 3 - Concept Document Content

implementation processes, are essential. To be useful, it must be current. The design team will ignore an obviously out-of-date Concept. Up-dates released at each major review in Figure 1 would be preferred.

4. *Let it evolve with the design.* Although the concept will levy operations requirements on the design, the concept should be allowed to change (configuration controlled) if the design effort indicates more efficient or less costly ways of implementing the requirements. In some cases, the requirements themselves may also evolve with the program.

5. *Keep its focus user-oriented.* The focus must be on the eventual operation of the MOS to achieve desired mission objectives, and on the users that must operate it.

4. REQUIREMENTS AND DOCUMENTATION.

In most programs, the definition of the initial operations concept usually occurs in parallel with the formulation of top-level mission and science requirements that will later govern the design. The Operations Concept, while not a requirements document per se, must be translated into requirements specifications that will implement the desired concept. Requirements specifications are essential to establishing a

common understanding between customer and contractor as to what the task must include and what the job must accomplish. Agreement on the requirements before proceeding to design is critical to efficient, cost effective, and on-time development of a system that will meet the customer's needs. In addition, requirements documents provide a source of test objectives for the program test phase as well as providing a valuable archival reference during the remainder of the program. For these reasons, the Operations Concept developer must understand the various types of requirements that are levied both on spacecraft design and on a MOS.

Mission requirements are high level statements of the goals and objectives of the mission itself, or in other words, what it is that the mission is required to achieve. Mission requirements may reflect such issues as the type of orbit necessary, the mission duration to achieve the objectives, number of spacecraft contacts per day, and/or spacecraft pointing accuracy.

Parallel to these are the *science requirements*, which define the goals and objectives of the science experiments, in many cases further delineating the mission requirements. Examples of these are specifications of the target characteristics to sense, the resolution of the data to be obtained and the frequency range of an instrument.

Operations requirements are MOS design requirements relating specifically to the ways of achieving the operational mission. In general, they define the scope of the ground activities within the MOS. They specify issues such as the number and type of ground antennas for spacecraft contact, the necessity for around-the-clock monitoring of vehicle activities, the types of computational activities that must occur, how experimenters will gain access to their data, and whether or not command sequences are validated with a simulator. At this level, the ground system can be treated as a series of black boxes, where the operations requirements define the functionality of the box (what it needs to do) and its interfaces with other boxes, but do not delve into the details of how the correct product is achieved. However, to design the black boxes, each operations requirement must be decomposed into one or more functional requirements.

Functional requirements are those that govern the design of the system components (to satisfy science, mission, or operations requirements) by identifying the specifications for each function the component must accomplish. The primary emphasis of functional requirements is on *how* the system is implemented rather than what the component does or the content of its operational product.

Lastly, *performance requirements* are those which specify when functions or activities must be completed, how fast and their duration. They delineate the order in which tasks must be performed, the amount of time allowed for an activity to be accomplished, other activity milestones that must precede or follow given activities, and resource constraints imposed, especially when computer operations are involved.

Figure 4 is a document tree for a typical spacecraft mission operations system. Not all of these documents are required for every project, nor are all the documents shown that a given project may need. Those documents on the far right are those developed during the design and build of the spacecraft but which are essential to retain and to *maintain* during operations. They do not fit specifically into a MOS document tree, but instead supplement it. To the left are those documents that are developed with the operations phase of the mission in mind, although they may be written very early in the life of the project. Along with the initial concept of operations, both the mission requirements and the science requirements are derived. The MOS Design Requirements document specifies how the mission and science requirements are converted to operations requirements to achieve implementation of the spacecraft operations activity. These, in turn, are decomposed into the functional requirements which are recorded in FRDs for both team activities and for the ground data system. For the latter, functional requirements documents are followed by hardware and software requirements and design documents and either

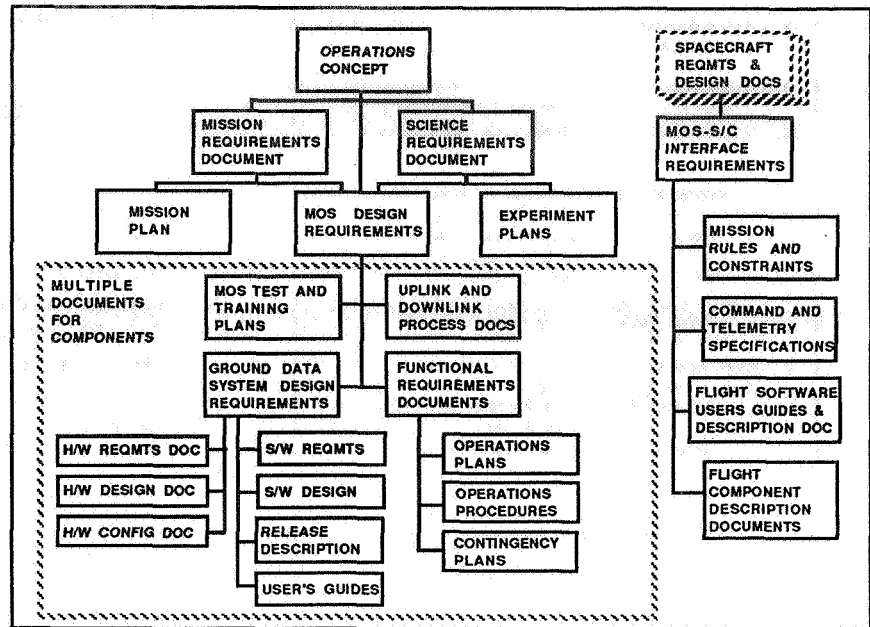


Figure 4 - Typical Document Tree

configuration documents or users guides. For the teams, the FRDs are followed by operations plans and procedures.

5. SUMMARY.

This paper has defined an Operations Concept as a part of a structured process for design and development of a mission operations system (MOS). It has discussed the program phases, required reviews and documentation necessary to achieve a complete, efficient and cost-effective MOS. It emphasized the importance of the Operations Concept, written early and maintained, and stressed the need for complete definition and agreement on requirements before the design has proceeded too far to easily modify. In short, a well-written, complete and maintained Operations Concept document will contribute significantly to a well-designed, efficient and cost-effective MOS.

6. REFERENCES.

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2. U.S. Air Force Regulation 57-1, Attachment 5, *Operations Concepts*, 1977.